CHAPTER 10
FOUNDATIONS

10-1. Introduction. This chapter discusses the design of foundations to resist earthquake lateral forces. Reference is made to SEAOC 1J.

10-2. General.

a. Base. The base of the building is the level at which the earthquake motions are considered to be imparted to the structure. From the point of view of design, the base is the level at which the base shear is resisted. In a building without a basement, this is simply at grade, where footings develop lateral resistance. In a building with a basement, the base is at grade if grade-level framing or the upper portion of the basement wall is capable of developing the required lateral resistance, or at the basement level if the lateral resistance cannot be developed at grade level. On sloping sites, the level at grade may be unrestrained at the downhill side but restrained, like a basement, at the uphill side. The base of a building is determined by judgment, considering the mechanism for developing lateral resistance. The base should be taken at the highest level where the building can transmit lateral forces into the ground on all sides. Partial basements and sites with varying subsurface conditions are also potentially troublesome. The engineer should consider how the forces enter the substructure and how they are transmitted into the ground. Simple three-dimensional free-body diagrams of whole substructures may be of great help in defining the design conditions.

b. Column bases. If a column is assumed to be fixed in the analysis of the superstructure, the foundation system must have the strength and stiffness required by this assumption.

c. Development of forces into the foundations. Foundations must be detailed to develop the horizontal and vertical components of seismic forces imparted by columns, shear walls, and braces. In instances where footings are subjected to lateral thrusts due to applied vertical loads, such horizontal thrust will be added to the lateral seismic force indicated above. An example of this case could be the outward thrusts on footings of a rigid gable bent due to applied vertical loads.

d. Interconnection of foundation elements. Unless the soil is quite stiff, foundation elements should be interconnected to allow a redistribution of lateral forces. Individual pile, caisson, and deep pier footings of every building or structure in Zones 2, 3, and 4 will be interconnected by foundation ties or a structural slab. For Zone 1, provide ties only when surrounding soil has low passive resistance values. Isolated spread footings on soil with a low passive resistance will also be tied together in a way to prevent relative movement of the various parts of the foundation with respect to each other. The ties can be formed by an interconnecting grid network of reinforced concrete struts or structural steel shapes encased in concrete. As an alternative, a reinforced concrete floor slab, doweled to walls and footings to provide restraint in all horizontal directions, may be used in lieu of the grid network of ties. Slabs on grade will not be used as ties when significant differential settlement is expected between footings and slab. In such cases, slabs on grade will be cut loose from footings and made free-floating (note that the effective unsupported height of the wall is increased for this condition). Strut ties placed below such slabs will be cushioned or separated from the slab such that slab settlement will not damage the slab or strut ties. Alternatively, it may be more economical to overexcavate the soil under the footings and recompact to control differential settlements under vertical loads and to increase passive resistance of the sides of the footings under lateral loads so as to eliminate the need for footing ties. Slabs on ground when used as a foundation tie will have minimum reinforcing according to ACI 7.12. As a minimum, a mat of #4 at 16 inches each way is recommended.

e. Overturning. The overturning moment at the base of the building is resisted by the soil through the foundation. The total load on the soil is not changed, but there is a change in the distribution of the soil pressure. For isolated spread footings, the design requirement is simply to provide for vertical components of the overturning moment in combination with the vertical forces due to dead and live loads. For wall footings, there may be enlarged footings under the boundary members, and these will have increased loads as indicated above for isolated footings, but there will also be loads on grade beams or other connecting elements.

f. Differential settlement. Earthquake vibrations may cause consolidation or liquefaction of loose soils, and the resultant settlement of building foundations usually will not be uniform. For rigid structures supported on individual spread footings bearing on such material, excessive differential settlements can damage the superstructure. Stabilization of the soil prior to construction or the use of piles, caissons, or deep piers bearing on a firm stratum may be the solution to this problem.

10-3. Design of elements.

a. General. The mechanism used for the transmission of horizontal forces may be friction between floor slab and ground; friction between bottom of footing and ground; and/or passive resistance of earth against vertical surfaces of footings, grade beams, or basement walls. The overturning effects, which require a careful analysis of permissible overloads for the combined effect of vertical and lateral loads, must be considered in the foundation design. Net upward forces must be resisted by anchorage into the foundation. Stability against overturning must be provided for the short-time loading during an earthquake (or wind) without creating disparities in the foundation configuration that would result in significantly different foundation settlements due to gravity loads. These differential settlements could create more damage to the structure than the short-time deformations that might occur under the highly increased soil pressures due to earthquake effects.

b. Slabs on ground. Slabs on ground are often thought of as nonstructural but will in fact be nonstructural only if detailed to be unconstrained by adjacent elements. In seismic design the slab on ground should be utilized as a connecting, tying, stiffening element by suitable details of joints and reinforcing in the slab and at the edges of the slab.

c. Grade beams. Grade beams may be used to stiffen spread footings where columns are intended to have fixed bases; grade beams may also develop lateral resistance in passive pressure on their sides, especially if stiffened by an integral slab on ground. Passive resistance values vary greatly with type of soil and depth. Adequacy of passive resistance should be determined by the geotechnical engineer. Passive resistance or lateral bearing values are permitted only where concrete is deposited directly against natural ground or the backfill is well compacted. Passive resistance should not be used where the lateral bearing surface is close to an excavation unless such excavation is carefully backfilled with well-compacted material. The shear capacity of the soil between such bearing surface and open or poorly compacted excavation or a similar depression may be inadequate to provide the needed resistance.

d. Basement walls. Basement walls can develop passive pressure for normal forces. The comments on passive pressure for grade beams apply.

e. Spread footings. Spread footings resist vertical loads through bearing pressure on the bottom and resist horizontal loads through friction on the bottom and passive pressure on the sides.

f. Wall footings. Wall footings resist lateral loads through friction on the bottom.

g. Piles. Piles driven into soft surficial soils must transfer the base shear into stiffer soils at lower levels. This involves bending of the piles. Criteria for design should be obtained from the geotechnical engineer. Where subsurface conditions vary over the site, the effective lengths of piles in bending may vary. The resulting variation in relative rigidity causes some piles to carry more lateral load than others and must be considered in the foundation design.

h. Batter piles. The use of batter piles should be avoided. Their greater lateral stiffness relative to the vertical piles attracts most of the lateral forces to themselves, resulting in an unbalanced lateral load resisting system. Because the inclination of the batter piles is usually small, very large vertical components of force are developed between the vertical and adjacent batter piles. The pile cap must be detailed to accommodate these forces, and the caps may need to be stiffened by horizontal grade beams to prevent rotation under these forces.

i. Foundation ties. Ties will be designed to carry an axial tension and compression horizontal force equal to 10 percent of the larger column load. The minimum tie will be 12 inches by 12 inches with four #5 longitudinal bars and #3 ties at 12 inches oc.

j. Retaining walls. Refer to chapter 13.

k. Mixed systems. When subsurface conditions vary significantly across a site, it is sometimes effective to use mixed systems, e.g., combinations of drilled piers and spread footings. Geotechnical consultation is especially important for mixed systems in order to control differential settlements. The difference in lateral stiffnesses between the spread footings and drilled piers must be considered in the foundation earthquake design.

10-4. Foundation capacities.

a. Stress basis. Foundations are generally of concrete designed on an ultimate strength basis, but the resisting capacities of the soils are generally prescribed on a working-stress or service load basis. This condition calls for care in developing foundation design forces from the reactions given by frame analyses and care in interpreting the allowable soil stresses given by the geotechnical engineer. In no case will the footing size be less than that required for static loads alone.

b. Allowable stresses. The structural engineer and the geotechnical engineer should resolve potential conflicts between short-term and long-term effects. A pitfall in the design of footings that carry vertical components of seismic forces is to proportion the footing for large short-term loads to meet allowable stresses that are intended to control long-term settlements. The results may be excessive seismic design and unnecessary differential settlements.

c. Combinations of modes of resistance. Buildings generally have not had problems of sliding in past earthquakes. The mechanism of resistance is probably quite complex, including a number of modes of resisting working more or less simultaneously. In some cases it may be possible to combine friction, passive pressure, and other effects; however, this should be done only under the guidance of the geotechnical engineer.